OCTAVE-WIDE MATCHED SYMMETRICAL, RECIPROCAL, 4- AND 5 PORTS

Z-2

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ABSTRACT

Symmetrical 4- and 5 ports were matched over an octave by applying a matching technique, based on duality. Internal matching was introduced instead of external ; so matching inside the structure for optimizing the ratio of radial currents to tangential ones.

Introduction

Already many decades ago it has been proved[1] that a complete symmetrical, passive, lossless and reciprocal 5 port (star) had specific properties if matched : equal power split among the four arms but, in addition, a 120° phase relation between adjacent arms nearest the excited arm.

It was Riblet[2] who recognized that this matched version could be a very usefull component for a 6 port network analyser. He succeeded in matching over almost an octave by using impedance transformers at the outside of his 5 port.

It will be shown now that instead of this external matching, we used internal matching, meaning matching inside the structure. This way an octave-wide match could easily be obtained and applied also to a complete symmetrical 4 port (a cross) ; even to an almost complete one : the well-known 90° hybrid ring.

A complete symmetrical 4 port becomes a degenerate directional coupler when matched. However, when the structure has lost its rotation symmetry -but still has 2 symmetry planes left over- a 90° directional coupler is obtained e.g. a branchline coupler.

Riblet[3] has shown, that the coupling becomes frequency independent if the hybrid is matched. With his external matching he achieved very flat coupling, however, over a limited bandwidth[4]. We obtained nearly the double bandwidth by applying internal matching, while the coupling was still flat within a few tenths of a dB. All experiments have been performed in microstrip on 1,5 mm thick substrate of $\varepsilon_r \simeq 4$.

The symmetrical 5 port

In the disc -used by Riblet- radial -as well as tangential currents occur in such a relation that the boundary conditions are fulfilled. This does not automatically mean a matched condition. In view of wideband matching it is wise to start with a configuration, having already the lowest reflection. This seems to be the ring structure (Fig. 1a).

If port 1 is excited, we can simplify the structure by merely considering its half (Fig. 1b). If we choose the impedance Z_s of the ring equal to Z_o, then : $S_{11} = 0$ and $P_2 = P_3$ for ω_o (corresponding to $\lambda/4$) if we neglect the $\lambda/8^o$ open stub.

At about $2\omega_o$ the power P_3 as well as P_2 becomes zero, due to the $\lambda/4$ open stub, however, P_2 more frequency dependent because port 2 is $\lambda/2$ further apart. This means that for frequencies between ω_o and $2\omega_o$ P_3 decreases less selective than P_2. In order to be matched, P_3 must at least be equal to P_2. Therefore we made a bypass in length $2\,l_c$ and characteristic impedance Z_c (Fig. 2a). This impedance must be chosen rather high ($Z_c \simeq 2$ to $3\,Z_o$) because it is a mere correction of power splitting and matching. This means that the coupling at both ends of $2\,l_c$ -e.g. at port 1 and 3- will be rather weak, so $2\,l_c$ will become resonant with $\omega_c > \omega_{max}$.

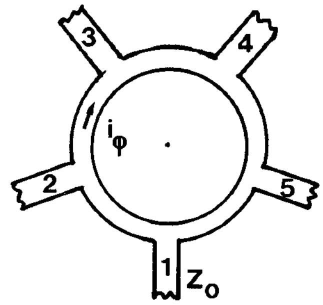

Fig. 1a : ring $i_\rho = 0$

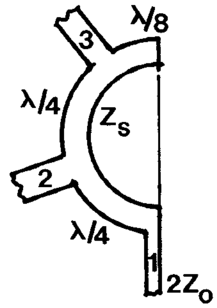

Fig. 1b : excitation at port 1

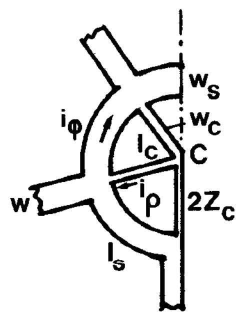

Fig. 2a : matched ring $i_{\rho,\varphi} \neq 0$

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Automatically now we have a compensation of the reflection, caused by the $\lambda/8$ open stub. In order to prevent spurious resonances and to keep the configuration completely symmetrical, we must also add a path between C and port 2. As Z_s and Z_c are parallel, we must reduce w_s in order to keep the total impedance about the same.

Finally we arrive at Fig. 2b. For our frequency band, ω_{min} to ω_{max}, where ω_{max} is $\geqslant 2\,\omega_{min}$, the matching has been determined mainly by $i\varphi$ so l_s and Z_s at ω_{min} and by $i\rho$, so l_c and Z_c, at ω_{max}. Around ω_{min} the open $\lambda/8$ stub can be neglected (Fig. 1b), so we have a quarter-wave impedance transformer to be matched, whereas at ω_{max} the influence of this stub is increasing.

Realization

A 5 port has been realized for the frequency band 4-8 GHz. The reflection at each port was smaller than 0,1. The power unbalance was not greater than ≃ 0,5 dB. The dimensions are given in fig. 2b.

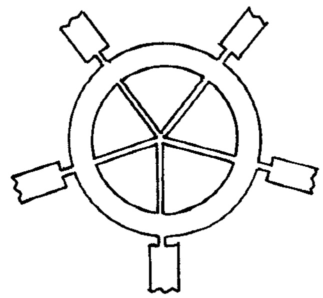

Fig. 2b : matched 5 port
$W = 3$, $W_s = 2$, $W_c = 0.5$ mm

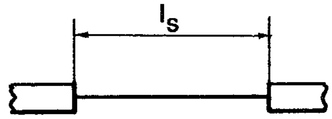

Fig. 3a : double step
$l_s = 18$ mm $= \lambda/2$ at $f_o = 5.2$ GHz

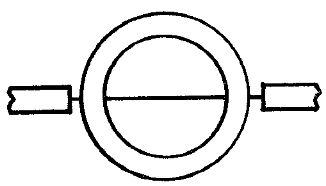

Fig. 3b : matched combination

The complete symmetrical 4 port

A matched -passive, lossless and reciprocal- 4 port is a directional coupler. It can be shown that this directional coupler degenerates in a peculiar cross -i.e. without any coupling to the side arms- if it is completely symmetrical. Well-known examples are : the resonant cross and -ring, having only in-line coupling. However, these are only narrow band solutions. How can this be realized broadband ?

A resonant ring can be broadband matched with a dual resonator, formed by a double impedance step (Fig. 3a).

This double step has no reflection at f_o ; max. reflection at ½ f_o and 1 ½ f_o. Almost over this range (1 : 3) it can be matched by coupling capacitively with a resonant ring (Fig. 3b).

In order to be symmetrical, we must add a branchline, so we arrive at fig. 4a. Now automatically, the side arms of the cross form short-circuited $\lambda/4$ stubs. These give some small reflection, which can be compensated by the ring as well. However, these $\lambda/4$ stubs restrict the bandwidth to somewhat more than an octave.

In order to obtain optimum match, the length of the ring had to be reduced with respect to l_s, which was increased with ten percent, resulting in the square "ring" (Fig. 4b).

Realization

With a capacitively coupled square ring we obtained : $\Gamma \leqslant 0{,}1$; $I \geqslant 20$ dB for 4 - 8 GHz. For the dimensions, see Fig. 4b. For microstrip, we need galvanic coupling, reducing the bandwidth to almost 25 percent (5,5 - 7 GHz).

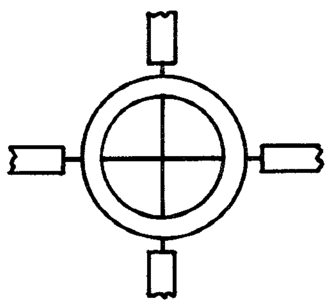

Fig. 4a : matched ring-cross

The crossed-branchline coupler

The complete symmetrical 4 port is just a special case of the branchline coupler.

We only have to make its arms -pair by pair- of higher (Z_p) and lower (Z_s) impedances (Fig. 5) than before, in order to stay matched. Even with the right ratio Z_p/Z_s for 3 dB, it does not automatically mean frequency independent powersplit as with external matching[3]. Its behaviour depends also on the amount of coupling with the cross and its resonance frequency f_c, determined by its length 2 l_c. Empirically we found $f_c \approx 1{,}1\, f_{max}$ a reasonable solution.

As we still have two planes of symmetry, the 90° phase relation between output signals (2 and 3) still holds as long as the 4 port is matched.

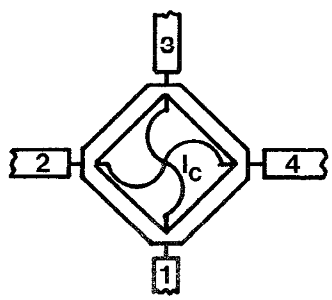

Fig. 4b : matched square "ring", coupled :
cap. $W_s = 2.5$ mm, 10 μm Mylar
galv. " = 2 " , 2 $l_c = 16$ mm
$W_c \simeq 0.3$ "

Realization

Although a planar 3 dB crossed coupler could be realized for an octave, its performance was moderate. Therefore, we concentrated on a coupler having a flatness within a few tenth of a dB ; an isolation over 20 dB and a reflection not exceeding ten percent. We succeeded in realizing one with almost 25 percent bandwidth (Fig. 5).

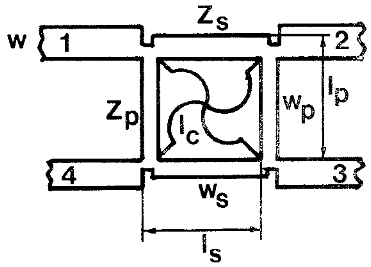

Fig. 5 : crossed-branchline coupler
$W = 3$, $W_s = 2$, $W_p = 1$ mm
$l_p \simeq l_s \simeq \lambda/3 \simeq 12$ mm
$2\, l_c = 1.2$ diag. $\simeq \lambda_c/2 \simeq 16$ mm
$W_c \simeq 0.3$ "
$f_o \simeq 5$ GHz

Conclusion

Our general matching principle based on duality was developed long ago[5]. For the first time it has been applied to a complete symmetrical 4- and 5 port as well as to a less symmetrical 4 port : the branchline coupler with 2 branches.

The duality relates to the fact, that in the structures radial currents i_ρ refer to a series behaviour, while tangential currents i_φ to a parallel one.

Internal matching may change both currents, whereas external matching only attacks the radial currents. Both can even be applied, because internal matching is most effective at the higher frequencies, external matching at the lower ones, resulting in a wider band and a greater length[4].

If the rings are capacitively coupled instead of galvanically, almost the double bandwidth can be achieved. This might be interesting for stripline or non-planar microstrip applications.

References

1 C.G. MONTGOMERY, R.H. DICKE and E.M. PURCELL, "Principles of Microwave Circuits", Mc Graw Hill, New York, 1948.

2 E.R. BERTIL HANSSON and G.P. Riblet, -The matched symmetrical five-port junction as the essential part of an ideal 6-port network - European Microwave Conf., Amsterdam, 1981

3 G.P. RIBLET, - A coupling theorem for matched symm. 2 branch 4 port networks -, vol. CAS-25, n°3, March 1978

4 G.P. RIBLET, -A directional coupler with very flat coupling-, vol. MTT-26, n° 2, Febr. 1978

5 F.C. de RONDE, -Full-band matching of waveguide discontinuities-, MTT Symp., Palo Alto 1966.